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THE SOUTH PASS JETTIES.

NOTES ON THE CONSOLIDATION AND DURABILITY OF THE WORKS, WITH A DESCRIPTION OF THE CONCRETE BLOCKS AND OTHER CONSTRUCTIONS OF THE LAST YEAR.

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Presented at the Eleventh Annual Convention, June 17th, 1879.

In presenting this paper to the Society it is not my intention to discuss the question whether or not jetties have been the proper means by which to improve navigation at the mouth of the Mississippi.

A few explanatory remarks to accompany the chart of the last channel survey (Plate XXXIX), and one or two tabular statements giving in a condensed form the results that are of interest, will enable a dispassionate judgment to be formed as to the efficiency of the improvement.

A year ago a paper was read before the Tenth Annual Convention of this Society, by Mr. E. L. Corthell, the Resident Engineer, wherein he says:

"It will be remembered that the jetties are still incomplete; that "the results aimed at are not yet fully realized, and that many of the "phenomena are the results of progressive works, and are incidents "simply of the progress of channel making, at which the river has been "set at work."

To-day, in reviewing the rapid progress which has been made in the construction of the jetties and in the improvement of the channel during the last year, we can promise the speedy completion of the work.

My object is to present some plans finally determined upon to insure permanency to the works, to explain the causes that led to their adoption, and to speak of the degree of durability attained in the construction of the jetties.

In doing so, I shall endeavor to make my remarks as comprehensive as possible by referring largely to illustrations.

Introductory Notes of Interest.

1. The East Jetty begins at the old eastern land's end, and is eleven thousand eight hundred (11 800) feet long.
2. The West Jetty begins four thousand (4 000) feet below the eastern land's end nearly opposite the western land's end, and is seven thousand eight hundred (7 800) feet long.
3. The Kipp Dam, six hundred (600) feet long, connects the head of the West Jetty with the west shore, and will be treated as a part of that jetty.
4. The jetties are one thousand (1 000) feet apart, and run parallel with each other.
5. The wing dams project out one hundred and fifty (150) feet from each jetty, and are of a temporary nature generally.
6. Both jetties terminate just beyond the crest of the old bar, two and one-quarter miles seaward from the old eastern land's end.
7. The jetties are built of willow mattresses and stone.
8. Both jetties, excepting the lowest one thousand (1 000) feet, may be considered permanently raised to the level of average flood tide.
9. The top of the mattress work where brought to the surface is twenty feet wide and covered with a layer of stone about one foot in thickness.
10. Tides are diurnal, and rise one and one-half feet.
11. The prevailing winds blow from an easterly direction.
12. The mean velocity of the river current during flood stages of the Mississippi is three miles per hour.
13. During the low water stage the current decreases to three-fourths of a mile per hour, and reverse currents have been observed.
14. Gales and hurricanes are liable to happen during the equinoctial months; highest velocity of wind observed, seventy-two miles per hour.

I.

Abstract of plans and specifications for consolidating the jetties at the South Pass, adopted and work commenced November, 1879.

The East Jetty to a point eight thousand feet and the West Jetty to a point nine thousand feet seaward, measured from the eastern land's end,

to be finished by a rounded paving of rip-rap stone on the top of the mattress work.

The centre of the pavement to follow the centre line of the jetty, the crest to be at the level of one and one-half feet above average flood tide, and the base to be twenty feet wide.

The stones to be set on edge as far as the lowest stage of the tide permits. The submerged part of the slope on the river and sea side to be built of rubble stone with an inclination of two to one.

In order to prevent leakage, gravel to be worked into the mattresses, and the top to be generally leveled up before proceeding with the paving.

Macadamized stone to be used to fill out the interstices between the larger stones composing the capping, and the slopes to be tightened in a similar manner by a liberal application of gravel and broken stone. No willow work to be visible, and the jetties to appear as though they were built of stone. On Plate XXXI may be found a section finished in the contemplated manner.

The remaining distance of both jetties, namely, three thousand eight hundred feet of the East Jetty and two thousand eight hundred feet of the West Jetty, to be consolidated by large blocks of cement concrete placed on top of the jetty. The blocks to be from sixteen to twenty feet long, from five to thirteen feet wide, and from two and one-half to four feet thick, the dimensions enlarging by off-sets as the jetties approach the sea ends.

The bottom of these blocks when put into position to rest at the plane of average flood tide, the jetties to be leveled up to that plane by large and small stone and gravel.

The blocks to serve as a foundation for a superstructive parapet, to be composed of concrete, and continuously built, from three to six feet wide and from two and one-half to four feet high.

This parapet to be applied to the lower sixteen hundred feet of both jetties.

A sufficient period of time to be allowed for the foundation blocks to settle before grading and leveling up, preparatory to the construction of the parapet.

From the upper end of the concrete work to a point six hundred feet above the extreme sea end, the river and sea slopes of both jetties to be composed of rubble stone, intermixed with macadam stone and gravel. The slope to be built with an inclination of two to one.

A rounded cap of paved stones to be carried from half the hight of the concrete foundation blocks to the lowest attainable water's edge.

For the lower six hundred feet of both jetties the sea slope to have a foundation, composed of a willow mattress, one hundred feet wide and two feet thick. On this foundation a sloping crib work to be placed, composed of palmetto piles, to be sunk by filling the compartments with large stones averaging about one ton in weight.

On the river side a similar crib work to be sunk on the rip-rap foundation already in place.

The vertical edges of the cribs to face the jetty and stand at a distance of from ten to fifteen feet from the embankment—the intermediate space to be filled with stone. Large rock to be used for covering the crib and making the connection with the concrete blocks on the jetties.

On Plate XXXII (Figs. 1, 2, 3), may be found an exhibition of the contemplated work.

The Pier Heads, at the extreme end of both jetties, to be built at right angles to the axis, and in form of a T-head to extend out on each side of that line. The foundation on the East Jetty to be one hundred and eighty feet wide and on the West Jetty seventy-two feet wide. As the surface is neared, the structure to contract so as to make the forward and side slope descend pyramidically into the Gulf, the foot of the slope on the East Jetty to rest one hundred feet seaward from the last concrete block. On the West Jetty the slope to project thirty-five feet.

In constructing this part of the work the area in advance to be leveled up by mattress work to a depth of sixteen feet below average flood tide, and thence raised to the surface by palmetto crib work held in place and covered with large stones.

The plans are subject to such modification as development of results may suggest.

II.

On the degree of durability attained in the construction of the Jetties, with an explanation of the causes that led to the adoption of the plans toward consolidation.

It will readily be understood that if these works have been as successful as it is claimed in deepening the bar at the mouth of the Mississippi from nine and two-tenths feet to twenty-seven and two-tenths

(27.2) feet, the question of their permanency must necessarily arise and involve the present and future value of the jetties.

The term "permanent" applies to all things that preserve and maintain the properties with which they have come into existence.

Strength being superlatively the original aim in the construction of sea works, *continuous* strength must be the essential for their permanency.

Hence it is obvious that the value of sea works will be proportional to the degree of strength which they possess, and, again, that any shortcoming on the part of the works, to fulfill the duties imposed, will be traced back directly to imperfections and defects in the mode of construction.

This mode of construction in the case of the South Pass Jetties has been a study in itself, as will be seen presently.

There were three destructive elements to be overcome by these works:

1. The abraiding power of the river current.
2. The momentum and impact of the waves.
3. The undermining power of the waves.

With a full appreciation of the magnitude of these forces, no design was made nor was any detail allowed to be put into the works which did not strictly adhere to the following practical laws:

1. That a broad and elastic foundation will prevent undermining.
2. That proper slopes will resist the impact of the waves.
3. That tight work will stop leakage, and
4. That work maintained at a uniform hight will obstruct the escape of water by overflow.

In these four points, or rather in their homogeneousness, lies the secret of permanent work.

The peculiar conditions under which this work has been carried on, and the many embarrassments and disadvantages which surrounded it from the start, are facts which have been well known.

At this place, and bearing upon the subject treated in this paper, I will only say that as a matter of necessity the execution of the works had to be governed in more than the ordinary sense of the word by rapidity and economy, leaving it for a future day to add such appliances as experience would suggest to maintain the strength of the works. The day to do this has arrived, as will be seen from the plans accompanying this

paper. They are the results of a long experience, a careful study and searching investigation of the phenomena which prevail in this locality.

In this connection it should be remembered that four years ago to-day, on the 17th of June, 1875, the first pile was driven in the work, and, a month later, the first willow mattress sunk close to the eastern land's end at the mouth of South Pass.

To-day the willow work may be regarded as completed, and the progress made towards consolidating the jetties by the application of heavier material has advanced far enough to foretell the period when this work will be completed, to stand an enduring monument of the capabilities of our profession.

During the construction of the mattress work the ratio of stone to willow was 1 : 5.32. This ratio may appear to be small, but it was found to be sufficient, as will be explained further on.

The specifications of the willow contract demanded flexible branches not exceeding two inches in diameter at the butts. The willows were brought a distance of about twenty-five miles. They grow in abundance along the banks of the Mississippi, above the head of the Passes, and overspread the small sub-deltas which have formed by deposits of the river at crevasses and lateral outlets where the waters have left the main stream and made a shorter road to the Gulf.

The willows were, therefore, easily obtained, cheaply transported, and were a material which, on account of its light weight, caused little wear and tear to the barges on which it was loaded.

Not so with the stone. The singular geognostic condition of the delta, followed by the total absence of rock for many hundred miles inland, made it a problem from the beginning how to procure the rock in quantities large and fast enough to allow the prosecution of the works with economy and rapidity.

During the early stages of the work, some rock—amongst which there was much granite—was obtained in New Orleans from the ballast of foreign ships. There were secured from this source nearly twenty-one thousand tons, brought from all parts of the world.

But under the pressure of incessant demand this supply soon became exhausted, and for a while rock was obtained from quarries near Vicksburg, Miss., five hundred and fifty miles distant from the jetties. This rock, however, did not answer. It contained a high percentage of loamy sand, and was brittle and permeable. The plan of drawing the supplies from that source was, therefore, soon abandoned.

The present contractors, Messrs. J. Sharp McDonald & Co., of Pittsburgh, Pa., bring the stone from quarries in the limestone region near Roseclair, on the Ohio river, thirteen hundred miles above the mouth of the Mississippi. The rock here is composed chiefly of calcareous, intermixed with quartzose elements, and has been found to possess fully the requirements of hardness, strength and weight, to make it serve the purpose for which it is intended. Weight, per cubic foot, 155½ lbs.

Rock, in any shape or size as it may be desirable for a special operation at the jetties, is furnished by the contractors in two monthly tows of about twenty barges, each barge containing an average of four hundred cubic yards of rock.

The preservation and care of the property destined for the construction of the works has been an item of great importance from the beginning, directly concerning the progress and often the safety of the works.

During the earlier stages, while the whole line of the works was much more exposed to the "abrading power of the current" and the "momentum and impact of the waves," it was a matter of unquestionable importance to always have the two materials, willows and stone, in readiness for immediate use in case damaged portions of the works needed repairing. A delay would cause tenfold the outlay of money.

The great aid which nature extended to these works in adding strength to them from its own sources (see deposit on sea side, Fig. 1 and 2, Plate XXXIII), was essentially hastened by uniformity in construction, which caused a uniform degree of tightness throughout and equable resistance to destruction.

While nobody will deny that a more liberal application of stone from the beginning might have hastened the formation of the channel, since it would have made tighter work quicker, we can unfailingly pronounce the saving in that quarter to have resulted in furnishing valuable data on the strength and dimension of cross-section required to resist the current of the Mississippi and the waves of the Gulf.

Under more auspicious circumstances, if, for instance, the whole amount of money appropriated for this enterprise had been available at the commencement of the work in June, 1875, precautional measures might have been resorted to, consisting chiefly of greater area of pier-section, which, although perfectly legitimate, would have been superfluous, as is shown by the course of events during the four years of jetty construction.

This point is illustrated by Figs. 1 and 2 on Plate No. XXXIII, Fig. 1 shows the manner in which it was intended to finish the pier section at a point four thousand two hundred feet seaward from the Eastern Lands-end, while Fig. 2, which gives the actual condition in which the jetty is built, enables us to compare the two. It should be stated that the foundation mattress on the sea side for a distance of three thousand feet was sunk under misconstruction of orders. No human engineering could have constructed a more sheltering protection than that which is obtained by the deep deposit of sand which has accumulated on the sea side over an area of many hundred feet in width, skirting both jetties in their march over the crest of the bar.

In explaining the causes that lead to so vast a deposit of sedimentary matter, the order in which the construction of the jetties was carried on furnishes the best criterion.

It will be remembered that the entire length of the foundation of the jetties, from the lands-ends to sea-ends was laid, before the second tier was applied; and again, that the entire second tier was placed and sunk on the foundation, before the third tier was commenced, and so forth, until the surface was reached.

The jetties have therefore been raised with a uniform degree of vertical progress over their entire length.

In doing this, it was observed that each tier of mattresses caused a shoaling on the sea side corresponding in hight with the thickness of the mattresses in place.

This was due to the obstruction which was placed in the way of each successive layer of current, stopping the flow sufficiently to cause the sediment to precipitate on the other side.

As the jetties grew up, and commenced to confine the volume of the pass, the water was largely charged with additional sediment due to channel erosion. But, by limiting the potency of the current to the channel between the jetties, no suspending power existed to carry the load of sediment over that portion of the bar which was not jettied.

It was dropped therefore on the crest and on the landward slope of that bar, building up a chain of successive reefs, as the bottom neared the surface. New Pelican reef, Base-line reef, and Reef Extension (see Chart of Channel, Plate XXXIX), are such new formations.

The numerous advantages of the sea side deposit were fully appre-

ciated, and measures taken to induce by means, based upon the same laws, a similar deposit on the river side.

For this purpose, a system of wing or spur dams was built, each wing dam jutting out one hundred and fifty feet from, and at right angles to the main line of the jetty. Although rapidly constructed, and with no view to permanency, these wing dams have been most effective in giving protection to the jetties and hastening channel erosion. The current is stopped above and below the dams; the sediment drops and a bank forms.

On Plate XXXIV are two comparative sections of the channel between the jetties, Fig. 1 showing the condition before, and Fig. 2 the condition after the wing dams were built. The effects are plainly visible.

The channel between the jetties, although intended to be one thousand feet, is at present only about seven hundred feet in width; but while the channel depths are allowed to increase in proportion to the greater contraction of the channel way, the jetty embankments are removed behind a sheltering bank of deposit which is braced and stiffened, as it were, by the tilted mattresses composing the wing dams.

Of the entire length of the jetties all but the last two thousand feet at the extreme sea ends, have received these protective deposits on the river and sea side.

It is evident from the plates and drawings presented that ninety per cent. of the willow work composing the jetties is immovably bedded in the deposits of the river.

No such thing could have come to pass if the water of the Mississippi did not contain the vast percentage of sedimentary matter which it carries to sea annually. But in such a case there would have been no delta, no bar and no jetties. Thus, the sediment itself becomes one of the agencies in removing the deposits of centuries.

An opinion may now be formed of the durability of both jetties from their starting points to within two thousand feet of the sea ends.

Safety of foundation, proper slopes, tightness and protection from overflow being the points to be examined, it is believed that the following points have been conclusively proven:

1. That the foundation is absolutely safe.

2. That the slopes of the work are protected by natural slopes, formed of the mud, sand and clay deposited by the river.

3. That tightness has been obtained for the jetty embankments to a degree very nearly equal to that of the natural banks of the pass, the only difference being that the top mattress is not yet filled with the mud, and, therefore, the leakage not completely stopped.

4. That the protection from waste of water by overflow is checked to the datum plane of average flood tide.

Hence, referring back to the plans adopted for consolidating the first eight and nine thousand feet of the jetties, it will at once be seen that the only remaining point, on the strength of which the permanency of this part of the jetties might be questioned, has been carefully considered.

The compressive strength of the proposed paving, in combination with the gravel and small stone, that is to be filtered into the mattresses, will have the tendency of stopping any superficial or lateral escape of water, with the ultimate result of turning it into its legitimate course between the jetties.

Nothing has been said, so far, of the sea ends of the jetties, except the description of the plans designed for their permanency.

The term "sea-ends" applies to the lower parts generally, without clearly defining their limits. It is understood, however, that as soon as the jetties emerge from the shelter of the reefs, the degree of exposure increases, and continues to increase, until the extreme ends are reached.

By far the most troublesome parts to maintain have always been the lowest six hundred feet of both jetties.

In planning the construction of the lower ends, the expediency and importance of a larger pier-section were amongst the special features of the original designs. But, as has been already remarked, the vital point, upon which success depended most, was a rapid and economical construction. The money to carry on the works had to come from sources opened by the success which the works themselves would produce, and, under the weight of the circumstances, the area of pier section was increased but slowly in the beginning.

The repairs which from time to time became necessary, made it imperative, however, that, at the earliest possible moment, such measures should be taken as would bring up the lower ends of the jetties to the standard of strength required for their permanency. The plans adopted aim at the accomplishment of this purpose.

In the development of this subject it should be stated that in addition to the three destructive forces already mentioned, two new elements were here introduced, which became detrimental to the jetties and delayed rapid construction. We refer to the subsidence of the bottom and to the depredations of the worms.

The subsidence of the bottom and the natural compression of the willow work, are items that should be distinctly kept apart. But the analogy in the effects of both made it difficult to ascertain their extent correctly and separately.

However, the depression of the surface of the work has been carefully observed from bench marks, established on some of the best settled old piles. The co-efficients of shrinkage thus obtained with reference to the original depth were :

At the upper end $= 0.33 \times$ depth.
At the sea end $= 3.00 \times$ depth.

Both values include compression of willows and subsidence of the bottom, with the strong probability that the mattresses were equally compressed throughout, by yielding their elasticity, while the actual subsidence varied with the consistency of the bottom.

Accepting one-half of the total depression, as found at the upper end, as being due to compression, and the other half as being due to subsidence, we have the elements of an equation by which to ascertain the amount of actual subsidence which took place at the sea-ends of the jetties, namely :

$$S = 4d\left(1 - \frac{0.33}{2}\right) - d*$$

It was not until the fall of 1877 that, after adding tier upon tier of mattress and increasing thereby the weight of the whole structure, the foundation was forced through the quick-sands below, and struck a bed on the older, harder and firmer strata of bar deposit.

Near the extreme end not less than sixteen tiers of mattresses have been sunk, representing a vertical hight of twenty-six and three-fourth feet of compressed willow work. The original depth of this place was eight feet, from which we conclude that eighteen and three-fourth feet of the work are below the original bottom of the bar.

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* *d* stands for original depth of bottom.

It may be added that the rate at which this sinking proceeded was very marked in the beginning, but since the fall of 1877 the the tendency has greatly decreased, if it has not stopped entirely.

Engineers will understand the difficulties which surround the observer who tries to follow up a system of levels on a territory likely to sink with his bench marks a fraction of a foot daily. We can do no otherwise than regard the results coming from such sources as approximations.

As to the depredations by the worms it should be stated, that out of twelve months of the year, seldom more than three months have been favorable for the worm to work. During these three months, which embrace the low water stage of the Mississippi, September, October and November, the surface water is brackish at the mouth and in the Pass, and it is salty or nearly so from a depth of five feet down, near the end of the jetties and seawards (hydrometrical reading 1 010 at 60° temperature.)

During the construction of the jetties, the following facts have been elicited, bearing on this question:

1. No traces of worms have ever been found above a point ten thousand feet below the Eastern Lands-end.

2. Below that point ravages of the worm have been observed, chiefly resulting in honey-combing the lower parts of piles and mattress binders, as also attacking the butt-ends of willows.

3. No worm-eating is found to exist on any material from the surface to a depth of five feet below. From this point it may extend to a distance of about eight inches below the bottom.

By the more liberal application of stone during the past two years, the willow work at the sea ends has generally been kept well covered, and has thus received a protection against the continuance of injury from the worms. Not much damage has come from that source during the low water seasons of 1877 and 1878.

In January of the present year, a board of officers appointed by the President, visited and examined the works. Touching this subject, the following is said in their report:

"The teredo does not attack wood where the free access of sea water is impeded. Those portions of a stick buried in mud or sand, or packed around with mud or sand, are secure. We have no reason to believe that the teredo has penetrated or can penetrate far into the interior of the mattress courses; we have pretty good reason to believe that the founda-

tion matresses are and will remain secure; and probably also the bulk of the interior of the masses of willow work."

Quite recently an attempt was made to break off, at the extreme sea end of the West Jetty, some piles which were obstructing the palmetto work. These piles had been in place since March, 1877, and it was thought they could easily be broken off. But the inability of a powerful tug to do so, proved that the piles were still sound, and it was concluded to let them remain in place.

During severe storms or gales in the earlier stages of the work the superficial layers of mattresses suffered the greatest damage by being displaced, and thrown off, after the top of the jetties was dismantled of the stone that was placed there. The main object, therefore, to be gained from a consolidation of the lower ends of the jetties is to give them sufficient strength to resist such violent action of the waves.

Consolidation means compressive strength expended on solids and voids. It is evident that every tier of brush and every layer of stone in the jetties must have solids and voids.

At the upper part of the work the sand, mud, and clay of the Mississippi has been so firmly embedded in the meshes of the mattresses, and between the interstices of the stone, that very little additional compression is needed to make the work tight and permanent. But, as the jetties approach the sea end and come in contact with the clean salt water of the Gulf, experience showed that the sediment, which had accumulated between the willows and stones during a high stage, would speedily be removed during the subsequent low stage of the Mississippi. As a result the river sustained a considerable loss of water by leakage and overflow, where the volume was needed most, to serve the purposes of channel making.

It has been estimated by careful simultaneous gauging that nearly twenty-five per cent. was abstracted from the volume passing the Landsend at East Point, before it reached the mouth of the jetties. Of this loss the far greater part escaped through and over those portions of the jetties which extend beyond the sheltering protection of the reefs and shoals. It increased at the same ratio as the degree of exposure toward the sea ends, and it became evident that compression by weight would be the only cure for the evil.

While the efficiency of rubble stone for consolidating the upper parts

of the jetties could not be questioned, the requirements of weight and strength, sufficient to resist the shock of the waves at the sea ends, could not be obtained from the largest sized rock, which it was practicable to bring from the distant quarries.

About two years ago, as an experiment, quantities of large rock, weighing from one to two tons apiece, were, at considerable expense, placed upon the lower ends of the jetties. But in a severe gale, which occurred a few months later, these rocks were lifted up by the waves, rolled over the jetty embankment, and deposited on the leeward slope, thereby adding, per chance, to the strengh of that slope.

In selecting a material which would effectively consolidate the sea ends of the jetties, it was important to bear in mind that gales along the Gulf coast are generally attended by high flood tides which have been observed to rise from three to four feet above the level of ordinary tides; these call into existence an enormous lifting power that can only be overcome by equipollent means of resistance.

For this reason, and in order to accomplish a permanent consolidation, something more powerful than quarried stone had to be resorted to. The plans of capping the last thirty-eight hundred feet of the East and twenty-eight hundred feet of the West Jetty, with blocks, made of cement concrete, provide for an application of from twenty-five to seventy-two tons in solid blocks. Their dimensions have been so chosen, as to impart great stability, and to dismiss at once all possibility of upsetting.

Cement concrete and lime concrete, have been largely used for important marine works at home and abroad. The Prussian harbors in the Baltic, the improvements of the French harbors of Toulon and Marseilles, the gigantic fortifications at Cherbourg, which were raised from a depth of twelve fathoms of water; again, the works of the harbor of refuge at Dover and the Island of Alderney, Great Britain, the foundations of many lighthouses, graving docks, break waters and sea dykes, parapets and fortifications, are constructed of blocks, formed by one method or the other, of cement or lime concrete.

Two more recent engineering works, those at the Sulina mouth of the Danube, and those at Port Said, the terminus of the Suez Canal, are being consolidated in a manner resembling the one now under progress of construction at the South Pass Jetties.

I am not aware, however, that in the history of any of these works, record is made of blocks weighing seventy-two tons.

General Gilmore, in his work on limes, hydraulic cements and mortars, speaks of "huge artificial blocks, capable by their inertia of resisting the waves of the Atlantic," used in the protection of the Cherbourg breakwater. These blocks weighed forty-four tons, and seem to be the largest on record. The same author also mentions the use of "immense blocks of concrete" at Marseilles, "for the protection of the outer or seaward slopes of the jetties, which enclose the basins and docks of that harbor. The concrete blocks weighed about twenty-two tons each."

The smallest blocks which are being put on the South Pass Jetties, weigh about twenty-five tons each, and the largest seventy-two tons each, not including the parapet, which is to be built on top.

In perfecting the plans, the protection of the blocks by slopes has been carefully considered.

Slopes are produced by gravity and friction, both forces acting upon the particles composing the slope.

In order that the particles may be at rest and resist separation, weight should be expended in amounts equal to the force represented by friction. Hence, at places exposed to the waves of the sea, the weight of the material used in the construction of a slope, should be equal to the force represented by the waves, and the slope will be safe with the degree of declivity due to the weight of the material.

But, if the slope be composed of less heavy particles it must be flattened, and the oblique surface enlarged, so as to increase the area which receives and meets the waves.

The plans for slopes now under progress of construction at the end of the jetties, may be said to fulfill part of both of these rules.

From the early beginning, the important part of slope construction, so highly essential for the preservation of the works, has received due and careful attention.

Single stones, in considerable quantities, have from time to time been used in protecting the lower parts of the jetties, but during heavy gales the sea has been observed to pick up these stones and carry them seaward by the receding action of the waves.

In this manner, the sea was slowly set at work, to build up a slope of its own, the surface area of which would be in conformity with the weight

of the stones and the friction of the waves upon them. A slope of unquestionable stability might have been obtained in this manner, and by continually adding fresh supplies of stone. But, such a process would have been slow and very costly.

The section of work, Plate XXXII, Fig. 3, shows that by the introduction of a sloping crib or cell-work, constructed of palmetto logs, great weight has been combined with abundant surface inclination.

The object of this mode of construction is to obtain compartments of moderate dimensions, by which to hold in place the stone and gravel, which is used to sink them.

The palmetto is a species of the palm tree, which grows in the tropics. Its wood is highly fibrous, tough and corky. The fibres are most intricately interwoven with each other, very tenacious and strong, causing rapid wear on the tools of the carpenter. Silicious matter has been found in the bark. The wood is said to be impervious to the attacks of the worm, and weighs about forty pounds to the cubic foot.

III.

Recent Constructions at the end of the Jetties.

The mode of constructing and depositing the concrete at the South Pass Jetties is novel in many respects, and, with the aim of contributing facts that may be of value, for the information and study of those interested in such matters, I have prepared the following notes on the two most important parts, now under construction at the sea ends, namely: the concrete work and the slope at the sea end.

1.—Concrete Work.

(A.) Preparatory Work, Machinery and Implements.

Both jetties have been treated in the same manner, both having received an independent and similar share of the preparatory and auxiliary work.

The plan on Plate XXXV represents the immediate surroundings of the concrete mixer on the east jetty, ten thousand two hundred feet below the Eastern Lands-end.

On account of the shoalness of the water near the jetty, and, in order to facilitate the transportation of the material from the barges to the

storage wharf, the latter has been connected by a bridge-portion sixty-three feet long, with the deeper water in the channel.

The storage wharf, bridge-portion and wharf-head are founded upon four hundred piles driven at intervals of eight feet, and connected with a 5×14 inches cap, for the support of the flooring.

The cement house occupies the northeastern portion of the storage platform. It is a low building, nearly square, and without windows. The roof is covered with felting, a layer of liquid pitch, and fine sea shells. The climate is damp, and these precautions were necessary for the preservation of the cement.

All the other ingredients, namely, sand, gravel and broken stone, are piled loose at different places on the platform, ready for immediate use.

The mixer or mill is placed over the jetty proper, and consists of a 5 feet 9 inches cube, made of quarter-inch boiler iron, well riveted and held together by bands of flat and T iron.

This cubical box is suspended by two hollow cast iron trunnions, seven and one-half inches in diameter, which are riveted from the inside of the box to two diagonal corners opposite each other, and rest in a tower or frame work substantially built of heavy timber. The centre of the trunnion is twenty-two feet above average flood tide, and the mixer is revolved by a steam engine which stands on the wharf below.

The two views on Plates XXXVI and XXXVII, together with the plan on Plate XXXV, will materially aid in understanding this partly novel machinery.

It will be seen that the cubical box has been cut off horizontally on one of the corners, so as to obtain a triangular opening for admitting and discharging the material. A cover (*D*, plates XXXVI and XXXVII) is made of the severed portion, and a small hand crane is provided by which it can be lifted and shifted.

As the mixer has to be opened and shut once for each charge of concrete it is a matter of consequence to have the manipulation proceed as rapidly as possible. The method employed has worked satisfactorily.

When the mixer is filled it is closed by sliding the cover under the four clasps or lips, which may be seen on the drawing, and at once secured by four point screws. The hinged screws (*ss*) are then righted up and screwed with their nuts down.

To allow the rapid working of these six screws long handles have been attached to their upper ends.

The water enters the box through the hollow journal at (B, B) while the ingredients are being revolved. The tank (C) which supplies the water stands on the top platform and has a floating gauge attached to it which is watched by the man whose duty it is to shut the valve (A) when the requisite quantity of water is admitted. The engine in its turn fills the tank.

For the transportation of the dry material from the wharf to the opening in the mixer, and the lift of nearly forty feet in hight necessarily included in the operation, a steam elevator forty-two feet high has been erected on the river side, and close to the mixer.

Hand carts, constructed for this purpose, as an improvement on wheelbarrows, are used for conveying the ingredients to the elevator box (EE), where they are deposited in different layers alternately. The elevator box is of wood, lined with sheet iron, measuring 6¼x5¾x4 feet, with sloping bottom, and trap door facing toward the mixer. It is guided by cleats, which project between the vertical leaders (FF), and ascends until the bottom reaches the trough (HH), when the trap door is opened and the contents turned into the mixing cube. The trough, which guides the material, is also lined with sheet iron, and is kept covered.

The revolutions of the mixer to each charge number twenty-two; the time required is about two minutes and twenty seconds, which is sufficient to thoroughly incorporate the ingredients.

From the drawings it will be seen that a railroad track has been laid to facilitate the quick deposit of the concrete. This track follows the centre line of each jetty, and extends up and down stream from the mixer station sixteen hundred feet seaward and twenty-two hundred feet landward. A branch track on the sea side has also been built for a distance of three hundred feet, at the extreme sea end, to aid in the construction of the sea slope.

The top of the rail at the mixer is ten feet above average flood tide, and at the sea end it is seven and one-half feet above that plane, the descending grade being chosen to be of advantage when the cars leave the mixer with a load of concrete.

The bents are eight feet apart, each composed of two cypress piles of sixteen inches diameter at the butt end, driven through the cone of the

jetty. A 5x14 inches cap is set on edge and drift-bolted to the piles, and 6x8 inches stringers are laid in the line of the track for the support of the rail.

The piles in each bent are driven as close together as the width of the concrete block designated for the place permits. A few feet are generally added to allow for the placing of the moulds. Towards the sea end the bents have been well stiffened by diagonal braces and bearings.

The track above the mixer station is mounted on trestle work, the bents being 8 feet apart, as in the case where piles are used.

The "rolling stock" of this railroad consists, for each jetty, of one locomotive and one concrete dumping car (see illustrations, Plates XXXVI and XXXVII). The locomotive is set upon a truck, which was originally intended to be used for a second concrete car when it was expected to run the cars by hand.

But, under the necessity of more rapid means of conveyance, the demand for a locomotive became soon apparent. The one illustrated is constructed, almost entirely of old scraps, such as will collect in the shops of large works. It is propelled by an ordinary rotary engine, and has been extremely useful.

The cars used for the dumping of the concrete were made by the same firm who contracted for the mixers (Pusey, Jones & Co., of Wilmington, Del.). They are 6½ feet long, 4 feet wide, and 3 feet 3 inches deep, and made to contain about two cubic yards. They are strongly built, of quarter-inch boiler iron, and mounted 9 inches below their centre of gravity, on an iron axle 3 inches in diameter, which is riveted by a round plate to both ends of the car. With the help of two ratchet wheels and wooden levers permanently attached to the axle on each end of the car, the dumping of nearly 9 000 pounds of concrete is done almost automatically, and the car is easily turned back to its upright position by two men (see Plate XXXVI).

Special attention might be called to additional details of interest, but their discussion would occupy too much space. The drawings on Plates XXXVI and XXXVII show the mechanism of the work so as to be easily understood.

(B.) Method of Placing the Concrete.

The operations involved in this method are as follows:

1. The preparing of a level bed.

2. The placing of the moulds.

3. The conveying and discharging of the concrete.

4. The removal of the moulds and protection of the sides by stone.

A level and solid bed is one of the chief requirements for the successful formation of the concrete blocks.

A gang of men is detailed for this purpose, and equipped with shovels, picks and crowbars. They commence by first removing the larger rock from the top of the jetty, and throwing it over on the river or sea side, wherever it seems to be of most advantage.

Small flats with gravel and broken stone are then moored alongside, and the contents wheeled or thrown with shovels on the embankment, there to be distributed and leveled. Pains are taken to thoroughly incorporate the gravel and small stone with the willows of the old mattresses. The foreman is provided with a gauge staff, by which he is enabled, referring to the railroad track, to bring the surface of the jetty to a uniform level.

When the weather is rough, which is by no means a rare occurrence, the material is brought by cars from the storage platform at the mixer station, and dumped wherever it is needed.

The placing of the "moulds" is next in order.

The moulds are wooden boxes, whose inside dimensions correspond with the size of the blocks. Plate XXXVIII, Figs. 1, 2, 3 show details of a mould for the formation of a block twenty feet long, twelve feet wide and three and one-half feet thick. The moulds are composed of a thin flooring and uprights or stanchions, which are so fixed that they will hold the sidings in place temporarily until the concrete has hardened. To this end, inch boards are spread longitudinally on the jetty where the blocks are already finished. Cross ties or battens *(a, a, a)*, of 2×6 inches lumber are nailed to the flooring at intervals of four feet. Two uprights or stanchions *(b, b)*, are then put up in the center of the two end ties, opposite each other, and pieces of two inch plank *(c, c)*, twelve feet long, permanently nailed to them and raised to the proper hight three and a half feet above the flooring. The twelve stanchions *(d, d)*, are set next at right angle to the flooring, twelve feet four inches in the clear, there being always two for each cross tie. These stanchions are held at the lower end by a dove-tailed piece of square lumber *(e)*, nailed to the ties outside, and facing a corresponding notch on the outer side of each stan-

chion. The sidings, consisting of two inch planks, twenty feet four inches long, provided in each end with clamp hooks of one inch strap iron, are then set on the inside of the line of stanchions *(d, d)*, the hooks clamping the end sidings. (*See* end elevation, Fig. 2.)

The top planks *(f, f)*, on both ends, being fifteen feet long, are so placed that they project one and a half feet out on each side. They have two notches *(g, g)*, nine inches wide and one and a half inches deep, at the upper edge, for the reception of a stiffening plank *(h, h)*, with two iron clamp hooks on each end to clasp the siding at the edge. Wedges *(k, k)*, are used to hold the plank in position.

These moulds, constructed almost entirely without nails or spikes, are sawed out in parts and fitted by carpenters, and carried on trucks over the finished blocks forward to the place where they are needed. Here the flooring is laid down on the jetty, and the other parts are then quickly put in place.

It will be noticed that all the stanchions are on the outside of the box excepting the two at each end. These are inside, in order to permit the placing of the blocks within a few inches of each other.

As a rule every mould is pushed up close to the finished block above, and its position is verified by referring to the center of the railroad track.

The filling of the mould with concrete may begin immediately after this. The carpenters return with their empty truck, the men who level up the jetty proceed down stream, and the masons take their places in the mould to attend to the concrete as it is being deposited.

The concrete is made in single charges, measuring two cubic yards each. Each charge as soon as deposited in the car under the mixer, is taken without delay to the place where it is to be dumped. The time consumed in the transfer varies, of course, with the distance. But the speed allowed to the engine, being about twelve miles per hour, seldom more than one minute of time will be consumed in the run between the stations. The train stops directly over the monld, the two men on the front and rear platform release the pawls, which hold the ratchet wheels, and the concrete is dumped into the box.

The total time required for the transportation of the material contained in one charge, from the different depots to the moulds on the jetty, has been ascertained to be as follows :

	Min.	Sec.
1. From wharf to elevator box	7	55
2. From elevator box to mixer	3	43
3. From mixer to car	4	27
4. From station to station	1	00
5. From car into moulds		30
Total	17	35

The hand labor is so regulated as very nearly to balance the functions of the engine, and, in this manner, only fifty per cent. of the time required is really consumed, so that about nine minutes are required to make and place two cubic yards of concrete, or one hundred and twenty-three cubic yards in one day of ten working hours.

It should not be inferred, however, that this is an average of the daily work done. There are days when rapid progress will be unavoidably delayed by rough weather, or during extreme high water at spring tides. In such cases, the placing of the mould boxes is seriously impeded, and, in consequence, the mixer cannot be worked to as great advantage. One hundred cubic yards of concrete is a fair daily average on one jetty.

During the earlier part of construction, the concrete was rammed by masons in the moulds. But, of late, this process has been entirely abandoned, as it has been found that the vertical fall of from ten to twelve feet, from the car into the mould, leaves the particles in a far better state of compression than could be obtained through ramming.

The concrete, after being deposited, is stirred as little as possible and only shifted, while it is quite fresh, to fill up irregularities and keep the layers approximately level and parallel.

When the top of a mould is reached, the surface of the concrete is roughly leveled with a rake, and allowed to set without further disturbance. Another mould is then commenced, filled, and so on, one after another, according to the plans.

Four days after the setting has commenced, each block is coated on the surface with a plastering of mortar, composed of fifty per cent. by volume of American Portland cement, and fifty per cent. of sand. The depth at which this mortar is laid may vary from one to three inches. It is applied with the trowel, and all joints between the stones, and other irregularities that may exist on the surface, and near the edge of the mould, are well filled and smoothed off. The mortar is prepared in small

quantities, and the plastering done quickly. The box is finally covered with inch boards, and not disturbed again for two weeks. During that time, the sea and river side of the blocks are protected by a revetment of rubble stone.

At the end of two weeks, the concrete has become fully hard enough to allow the removal of the moulds. The wedges (*k*, *k*), Plate XXXVIII. Fig. 1, are then pulled out, the stiffening planks (*h*, *h*) removed, and the stanchions (*d*, *d*) and longitudinal sidings taken away.

The stanchions (*b*) and sidings (*c*), which rest close between two blocks, are left until some future day, when they may be removed, and the small interval filled out with mortar or rubble masonry.

(C.) Notes on Ingredients composing the Concrete.

The concrete is made of broken stone, gravel, sand and cement. The broken or McAdam stone is quite irregular in shape, being broken by hand. The size is specified in the contract, each of the stones is to pass through a ring, three inches in diameter.

The gravel is brought from Prophets Island, near Baton Rouge, La., a distance of two hundred and fifty miles above the jetties. It is obtained from the deposits at the mouth of a creek, which empties into the Mississippi, and is raised from the bottom by dredging. The pebbles vary in size from one-thirtieth of an inch to two and a half inches in diameter. The sand is delivered by schooners, and comes from the islands in the Mississippi Sound, near the mouth of Pearl River, Miss. It is a moderately coarse and sharp grained sand of white or pale yellowish color, the diameter of grains averaging about one-fortieth of an inch. It is dug up in a state of humidity, from a depth of several feet below the surface, and used as fast as it can be delivered at the works.

It may be stated that the quality of the sand, which is found in the more direct neighborhood of the delta, and on the reefs adjacent to the jetties, is not deemed suitable for the purpose of concrete making, as it is chiefly composed of fine and round particles of silicious nature, rarely exceeding one-seventieth of an inch in diameter.

In the table below may be found the percentage by volume of voids, and the weight per cubic foot, of the stone, gravel and sand, used in the concrete.

Material.	Percentage by volume of voids.	Weight per Cubic foot.
Broken Stone..............................	.489	79.50 lbs.
Clean Gravel..............................	.314	119.24 "
Sand	.333	79.72 "

The cement, which is employed at these works, is Saylors' American Portland cement, over five thousand barrels of which have been used to date. Careful tests, which have been made with it, have justified Mr. Eads in further recommending its use. The following table, condensed from numerous daily tests, and grouped, to save space, in the order of months, exhibits the results obtained from the tests of this cement. The testing is done on fineness, weight and tensile strength in conformity with the specifications of the contract, and in a careful manner.

For testing of tensile strength, a Riehle counter balance testing machine is employed. The briquettes represent an area of two and a quarter square inches in the section, but they are sufficiently enlarged on both ends, for the application of the clamps.

Condensed Table of Cement Tests—S. P. Jetties.

Month—1879.	Number of tests from which average is taken.	Seven day test, average tensile strength in lbs. per sq. inch of neat cement.	Percentage passing sieve, 2 500 meshes to sq. inch.	Weight per U. S. struck bushel in lbs.
February	155	285 lbs.	84	117.60
March	157	262 lbs.	87½	123.00
April..............	271	288 lbs.	84½	121.00
Average Result...	583	278$\frac{3}{16}$ lbs.	85$\frac{3}{16}$	120.53 lbs.

The cement is shipped from New York by steamer to New Orleans, and thence on barges to the store houses at the jetties.

Considering the damage to cement, which often results from transhipment by sea, the tests of three months at the jetties, are all the more satisfactory.

Saylors' Portland cement is a slow setting cement, which may be moderately restirred and shifted, without destroying its hydraulicity.

The market weight of a barrel of this cement is 380 lbs., or 133.33 lbs. per cubic foot. When gauged in this state of compactness, with $\frac{1}{3}$ measure of water, the paste will expand, so as to occupy 3.9 per cent. in excess of the volume originally occupied.

When piled loose, so as to weigh eighty-nine and a half pounds per cubic foot, and gauged neat, with enough water to make a paste of similar consistency, the latter will shrink until it occupies 80.7 per cent. of the volume originally occupied.

These deductions were important, in deciding upon the proportional parts of ingredients composing the concrete.

Minor points may have been changed, but essentially, the proportional parts have remained as follows:

15 parts	by volume	of	broken stone.
4.38 parts	"	"	gravel.
8.28 parts	"	"	Sand.
3.00 parts	"	"	cement (barrel weight).

It should be stated that the gravel in this estimate is clean gravel, referring only to those particles, which are rejected by a seive having three hundred and twenty-four meshes to the square inch. Thirty-eight per cent. by volume of the gravel, delivered at the works, will pass through such a sieve.

From this, and with the coefficients of voids, the net contents of one hundred cubic feet of set concrete, may be computed as follows:

1. Broken stone,	80.75 cub. yds.,	which gave	41.26	cub. yds.	of solids.
2. Clean gravel,	23.58 "	"	16.17	"	"
3. Sand,	44.57 "	"	29.73	"	"
4. Cement,	16.15 plus expansion	"	16.78	"	"
	165.05 cub. yds. of dry material make	....	103.94	c. yds.	of concrete.

From this the coefficient of shrinkage may be obtained:

$$S = \frac{103.94}{165.05} = 0.629.$$

The excess of 3.94 cubic yards is consumed in the final induration of the concrete. The figures have been computed from careful observations, and may be relied upon.

The ingredients are mixed with fresh water, in quantity equal to about ten and a half per cent. of the volume of the dry material. The amount is registered on the gauge.

(D.) Present Condition of Work and Observations on Concrete Blocks.

TABULAR STATEMENT SHOWING PRESENT CONDITION OF CONCRETE WORK, SOUTH PASS JETTIES.

	EAST JETTY.	WEST JETTY.
Total length of concrete in lineal feet, proposed to be laid	3 800 feet.	2 800 feet.
In place June 11th, 1879	2 097 "	2 324 "
Balance remaining, in lineal feet	1 703 "	476 "
Total amount of concrete, in cubic yards, proposed to be laid, including parapet	3 735 cubic yards.	3 087 cubic yards.
In place June 11th, 1879	2 071 " "	1 899 " "
Balance remaining, in cubic yards	1 664 " "	1 188 " "

By far the greater and most difficult part of the concrete work is already in place. On the East Jetty the lowest block is within one hundred and sixty-seven feet of the extreme sea end, and on the West Jetty, the blocks have approached the end to within four hundred and seventy-six feet.

Operations are now chiefly confined to the upper end, where the smaller width of the blocks allows the work to proceed at the rate of one hundred and twenty lineal feet daily.

The weight of the concrete has been ascertained by actual test, and by computing the weight from the different dry ingredients, as follows:

Concrete green.............. 160 lbs. per cubic foot.
" thoroughly dry..... 149 lbs. " " "

The blocks, after removing the moulds, expose, generally, a uniform and smooth surface. Irregular places and holes are plastered by the masons.

In regard to the construction of the parapet, it has not been decided yet, when it will be time to commence. The degree of subsidence displayed by the blocks will settle this point in course of time.

At present it may be too early, from the limited amount of observations, to discuss the probabilities involved in this question. It is clear, however, that the amount of compression, exacted by the tremendous weight of the blocks, will continue to act upon the elasticity of the subaqueous layers of mattresses, until the same is ultimately destroyed.

A complete record, ascertained by careful and frequent periodical levelings, is kept of each block, and the elevations are compared with the original plane, at which the blocks were set.

There seems to be a general tendency, on the part of the blocks, to settle within the first ten days of their construction, and then to remain stationary or nearly so for an indefinite period.

The impetus imparted by the sudden application of so great a weight is evidently the cause of this action.

The subjoined tables are given to further illustrate this subject:

TABLE 1.

SHOWING SUBSIDENCE OF CONCRETE BLOCKS, AT DIFFERENT PERIODS, ON EAST JETTY.

Number of contiguous Blocks from which average is taken.	Net Weight of mass of Concrete under consideration, in tons of 2 000 lbs.	Initial Elevation of top of blocks above av'ge flood tide.	Date when placed.	Date when levels were taken.	Elevation above A. F. Tide at those dates.	Elevation above A. F. Tide on June 11th.
	Tons.	Feet.			Feet.	Feet.
4	110	3.00	Feb. 2.	Feb. 10.	2.685	2.480
4	136	3.00	" 12.	" 20.	2.440	2.140
4	136	3.00	" 18.	" 20.	2.790	2.600
4	150	3.00	" 24.	Mar. 4.	2.605	2.415
4	150	3.00	Mar. 4.	" 14.	2.610	2.406
4	193	3.50	" 8.	" 14.	3.351	3.150
4	193	3.50	" 11.	" 25.	3.440	3.328
4	288	3.75	" 15.	" 25.	3.533	3.373

TABLE 2.

SHOWING SUBSIDENCE OF CONCRETE BLOCKS, AT DIFFERENT PERIODS, ON WEST JETTY.

Number of contiguous Blocks from which average is taken.	Net Weight of mass of Concrete under consideration, in tons of 2 000 lbs.	Initial Elevation of top of blocks above av'ge flood tide.	Date when placed.	Date when levels were taken.	Elevation above A. F. Tide at those dates.	Elevation above A. F. Tide on June 11th.
	Tons.	Feet.			Feet.	Feet.
4	110	3.00	Mar. 21.	Mar. 24.	2.912	2.854
4	110	3.00	" 24.	Apr. 7.	2.930	2.785
4	136	3.50	" 27.	" 7.	3.262	3.131
4	136	3.50	" 29.	" 7.	3.200	2.981
4	136	3.50	Apr. 1.	" 7.	3.410	3.041
4	150	3.50	" 6.	" 18.	3.420	3.343
4	150	3.50	" 8.	" 18.	3.130	3.083

2.—SLOPES AT THE SEA END.

The construction of the sea and river slope by palmetto crib work, as proposed for the lowest six hundred feet of the jetties, was not commenced before the month of April of the present year. Plate XXXVIII, Figs. 4 and 5, represent a sloping crib, fifty feet long, twenty-two feet wide, and five and a half feet high, intended for shoal water.

Before the dimensions of a crib are given to the carpenters, a careful investigation is made, embracing depth of water and condition of bottom, on and near the place where the crib is to be placed. Referring to the one on the drawing, there are fifty-one palmetto piles (*A*, *A*, see Figs. 4 and 5), each twenty-two feet long, which are placed in one row, one foot from centre to centre, on the inclined ways, formerly used for mattress building.

This being the floor of the crib, a second row, consisting of five logs (*B*), is placed to break joints with the flooring, at distances of five feet from centre to centre. In the same manner the third row is placed, consisting of eleven piles, sixteen and a half feet long, at distances of five feet between the centres, and breaking joints with the lower row.

Augur holes are then bored, and the rows bolted to each other by one inch bolts. The fourth and fifth row of piles is then laid, as shown on the illustration, and drift-bolted to the lower layers.

The crib is braced by short logs (*C, C*), standing upright against the corners of a cell. Their lower ends are flattened, and wedged tight between the flooring, where they are fastened by bolts.

In addition to this, stirrup bolts are used at every alternate corner of a compartment, which tie all the logs from the bottom to the top.

The compartments are four feet square in the clear, and large enough to admit the largest bowlders that are brought to the jetties.

The cribs are pulled off the ways and into the river by a tug, which takes them at once to the place for which they are built.

Here a row of guide piles has been driven, about ten feet from the jetty embankment, to which the vertical edge of the crib is lashed. The sinking may then take place. The compartments are finally closed by immense bowlders, which are lifted into position by a derrick.

The remaining space of about ten feet in width, between the vertical edge of the crib and the jetty embankment, is filled with stone until it appears above water.

At some of the cribs the flooring has been constructed of palmetto logs, split lengthwise through the centre, but it is quite immaterial to the strength of the crib; besides, the labor involved in cleaving the logs, hardly justifying its constant application, it was only resorted to when the supplies ran short.

APPENDIX A.

Explanatory Remarks on the Chart of Jetty Channel, Plate XXXIX.

The soundings are made by the United States Engineers. In the earlier stages of the work they were made once a month; now a complete channel survey is made only four times a year.

The chart on Plate XXXIX has been so arranged as to be nearly self-explanatory. The figures enclosed in circles denote the depths in May, 1875, all the others the depths to-day.

From the comparison, we ascertain one positive fact, namely: That the depth on South Pass bar has increased from nine and two-tenth feet,* to twenty-seven and two-tenth feet. This is the result of four years work.

* Although depth of 9.2 feet is shown on the United States Coast Survey Charts of May, 1875, we found it impossible to get our tug boats, drawing only seven feet, over the bar, before our works had made any impression upon it. For this reason, Mr. Eads very properly claims that the maximum depth on the bar was not more than eight feet when the work was commenced.

All matters relating to the regimen of the river, the general principles upon which the construction of the jetties was based, the numerous interesting phenomena connected with these works, and, above all, the surprising changes in the Gulf bottom, beyond the end of the jetties, have been exhaustively treated by Mr. Corthell, member of the Society, in his paper, read a year ago.

It may simply be added, that after having arrived at the end of another year, and produced new and valuable results, the arguments become doubly strong.

The chart presented a year ago, indicated that there was a navigable channel of twenty-two feet over the bar. The increase in navigable depth during the past year has been, therefore, five and two-tenth feet, with corresponding ameliorations in the channel above. Still, the past year has been comparatively short in regard to work.

The epidemic, which raged in the South, made it necessary to suspend the works temporarily. This suspension lasted four months, and was complete, nothing was done toward maintaining the works. In their unfinished condition, they were left, as it were, to take care of themselves, embracing in that period two of the stormiest months in the year—September and October.

In my personal intercourse with members, interested in this improvement, the opinion has been expressed, that the suspension of the works would entitle the last year to be called a test year.

This opinion seems just, and the reports giving channel depths, made directly after work was resumed, at the end of November, were looked upon with more than usual interest. It is safe to say that these reports showed no deterioration. The first official survey, made by Captain M. R. Brown, Corps of Engineers, U. S. A., the United States Inspecting Officer, showed on December 6th, 1878, a navigable channel of twenty-three feet depth, while on July 15th, it was only twenty-two feet.

The gradual increase of depth on the bar, since the commencement of the works, is given in the following table :

Date.	Navigable Depth in Feet Below A. F. T.*	Date.	Navigable Depth in Feet Below A. F. T.*
May, 1875........	9.2	October, 1877.....	21.0
January, 1876.....	11.0	January, 1878....	23.0
April, 1876........	17.0	April, 1878.......	23.0
July, 1876........	20.0	July, 1878........	22.3
October, 1876.....	20.3	October, 1878.....	23.0
January, 1877....	20.8	January, 1879....	23.9
April. 1877.......	20.9	April, 1879.... ...	27.2
July, 1877........	20.3		

* A. F. T—abbreviation of Average Flood Tide.

It will be observed that the improvement has been a progressive one, generally, although retardations and fluctuations, in the formation of the channel, have not been uncommon.

In the preceding pages of this paper, the trouble which was experienced in protecting the sea ends of the jetties has been referred to, as also the loss which resulted from considerable portions of the volume being withdrawn when its energy was needed most. Connecting these incidents with the sudden and marked deepening which occurred between the months of January and April, 1879, while the concrete blocks were being placed, it is but proper to accredit the greater share of the retarding and fluctuating influences at former periods to causes directly connected with the loss of volume.

Detailed statements of events which followed the cure of the evil will therefore be regarded with interest.

The following table gives the relation between the progress of the concrete work and the channel scour :

Date. 1879.	Terminus of Concrete measured Seaward from East Point, in feet.		Lineal feet of Concrete in place.		Navigable Depth on Bar, in feet.
	East Jetty.	West Jetty.	East Jetty.	West Jetty.	
	Feet.	Feet.	Feet.	Feet.	Feet.
Jan. 20..	10 474		382		23.9
Feb. 13..	10 798	10 372	706	240	23.9
March 14..	11 511	10 372	1 419	240	24.8
" 27..	11 633	10 680	1 541	548	26.7
April 8..	11 633	11 202	1 541	1 070	27.2

In addition to the many phenomena developed in the construction of these works there is still one which I believe has never been alluded to before. I refer to the conspicuous turn which the channel makes in emerging from its confinement between the jetties.

This turn is in an easterly direction, and has never been marked more prominently that at the present moment. It engages at once our most attentive consideration.

During the earlier stages of bar erosion the tendency of forcing an outlet in an easterly direction was but feebly marked. The section of the channel at the jetty ends was almost uniformly flat, resulting from the incomplete condition of the jetties and the struggle of the current to reach the level of the Gulf in every possible direction. Still, the slight depression which existed to mark the width of the channel, even at that time, was located on the eastern half of the section.

It seems difficult, consulting the records of our observations, to find positive assurance for an explanation of the phenomena of this eastern outlet.

At a place so full of the exhibits of unexplored elements the experience which four years represent is but meagre and incomplete.

The reasons *pro* and *con.* are many on both sides, and while it might be plain to the minds of some that the phenomenon is caused by the sudden relief of the volume under head, others might claim that the condition of the bottom on the east side was such as to hasten scour. But, although both may have their share, the main point toward a reasonable solution of the problem seems to rest in the fact that the prevailing winds, the tides, and salt water currents approach the jetty mouth from an easterly direction, and that the relation existing between these forces causes the salt water to continually pass under and encroach upon the fresh water which the pass discharges in flood stages of the river, thereby crowding and deflecting the lower stratas, with their heavier ratio of sediment, over to the west side of the mouth.

In support of this supposition, it may be stated that observations at every high stage of the river have shown the depths over the western area to have diminished, while, at low river, when the salt water has unobstructed admittance to the mouth, the depths increase from causes that cannot justly be attributed to any scouring power due to the jetties.

In addition to this, it can be stated that at the end of every low river the depths on the west side have increased over those of the previous year at the same ratio as they have increased in the channel, and thoughtful reflection will point at once to the indefinite period which must elapse before the often raised question of extending the jetties seaward will demand serious consideration.

Such are the conditions as existing to-day.

A year ago conclusions of equal importance were arrived at. The intervening time has brought forward additional proofs in confirmation of the arguments used, and, while we are reviewing the past and prognosticating the future of the works, the ships of all nations, laden to their utmost capacity with the various products of the Mississippi Valley, bear witness to what has been accomplished.

APPENDIX B.

Explanatory Remarks on the Chart of the Head of the Passes, Plate XL.

The extensive system of dams and dykes, which is built at the head of the passes, exhibited on Plate XL, is the result of the gradual solution of a problem which is conceded to have been far more complicated in its details than any of those which presented themselves at the mouth of the river.

The head of the three passes of the Mississippi is about twelve miles above the mouth of the jetties. The Mississippi, in approaching this point from above, gradually widens from twenty-six hundred feet to eight

thousand five hundred feet, where the river divides into the three passes.

As a result of this widening there existed at this point a shoal, common to all the passes, which extended from one shore of the Mississippi to the other. The depths on this shoal were proportionate to the size of the pass at whose head it was located. Thus South Pass, being the smallest, discharging only about ten per cent. of the volume of the Mississippi, had the shoalest entrance, the depth, that could be carried into the pass, being not over fourteen feet.

In the table on the next page may be found the chronological history of the works constructed for the improvement of this shoal.

The original design for the improvement of the head of the pass contemplated the closure of the Western Channel alongside of the Island which divides the entrance into the Pass at its upper end. But, by reference to the map (on Plate XL), it will be seen that the channel, which is now the highway of commerce, instead of lying to the east of the island, is located on its western side. The causes which led to this radical change of design constitute one of the most curious and interesting portions of the history of this work.

It was believed that the construction of the East Dyke alone would increase the depth of water at the head of the pass to such a degree as to avoid all question of the right of Mr. Eads to receive his first payment of $500 000 from the Government. This payment was to be made after securing twenty feet in depth through the channel at the mouth of the pass. His obligations to deepen the shoal at the head of the pass were not clearly defined, and the difficulty in raising money to carry on the work in the face of the doubts and opposition which the enterprise elicited made it of the first importance that no more means should be expended at the head of the pass than was absolutely necessary. It was believed that no further works at that locality would be needed until after the receipt of the first Government instalment.

At that period of time the channel through the jetties had developed so far as to justify the announcement by Mr. Eads that it was navigable for vessels of sixteen feet. This was denied by the opponents of the work, who asserted that a channel of barely twelve feet in depth existed. The United States inspecting officer was, therefore, instructed by the Secretary of War to measure the depth of channel, and give an official certification of the same, to correct the misrepresentations which were at the time seriously interfering with the negotiations for money with which to prosecute the work. At the same time it was claimed that material washed out from the Jetty Channel was reforming a bar immediately in front of the jetties.

A survey made about this time by the United States Coast Survey disproved this latter statement. A few days after, the Cromwell steamship *Hudson* entered the Pass without any difficulty, drawing over fourteen

TABLE,

GIVING RECORD OF DATES RELATING TO THE CONSTRUCTION OF THE WORKS AT THE HEAD OF THE PASSES

No.	Name of Dam or Dyke.	Date when Commenced.	Date when Finished.	REMARKS.
1	East Dyke	Dec. 19, 1875	May 17, 1876	
2	Dam 1	July 19, 1876	Aug. 21, 1876	
3	Lighthouse Dam	Aug. 23, 1876	Sept. 6, 1876	
4	Island Dyke, from Point P. to New Cluster	Sept. 6, 1876	Oct. 26, 1876	Torn down April 10, 1877; rebuilt on Line P. R., between March 12th and April 17, 1879.
5	Lighthouse Dyke	Sept. [illegible]6, 1876	March 17, 1879	Was gradually pushed up stream by extensions, January 20, 1877, March 2, 1877, May 30, 1877, and March 17, 1879.
6	South West Pass Sill	Sept. 18, 1876	Jan. 31, 1879	The foundation was in place on November 6, 1876, and the second, third, and fourth tiers were laid between December 9, 18.8, ann January 31, 1879.
7	West Dyke	Sept. 18, 1876	Dec. —, 1878	
8	Island Dam	Jan. 25, 1877	Feb. 13, 1877	
9	Island Dyke, from Island to Point P.	Feb. 3, 1877	April 5, 1879	The foundation was in place on February 13, 1877.
10	Pass A L'Outre Sill	March 21, 1877	May 8, 1877	
11	Upper Dam	April 2, 1879	June 4, 1879	
12	Island Dyke, from R. to T.	....	....	Under progress of construction.

feet; and a few days later a ship of the same line went out through the Jetty Channel drawing about sixteen feet.

The subsequent use of this channel by this line of steamers furnished for several weeks the only undoubted evidence which Mr. Eads was able to obtain of the remarkable improvement which had been to that date effected. But it was deemed absolutely necessary to increase the depth over the shoal at the head of the pass, to keep pace with the deepening through the jetties; and, in this regard, it was found that the East Dyke had not produced the effects which had been anticipated. The retarding influence which it exerted upon the natural flow of the water created a head above it, and this caused, in the course of a few weeks, as large a flow into Pass Á L'Outre as had existed before the construction of the dykes although the direction of the dyke placed its upper extremity six hundred feet to the eastward of the neutral axis of the current between South Pass and Pass A L'Outre. The reduced current below the head of the dyke, and to the west of it, caused a large amount of deposit to be thrown down, to the injury of the eastern entrance to the pass, while the western entrance had increased in depth about two feet.

To carry out the original plan, therefore, it would have been absolutely necessary to construct the dam between the island and the western shore of the pass, and to do this would temporarily have stopped the Cromwell steamers from the use of the jetties altogether. For this reason it was determined to change the plan and treat the western entrance in a manner similar to that which was designed to be applied to the eastern one, and accordingly the Eastern Channel was closed by "Island Dam," and the outlines of the present channel, on the western side, were fixed by the location of the dykes on that side, as shown on Plate XL.

The construction of the East Dyke developed the important fact that it was simply impossible to construct any works by which the flow into South Pass could be concentrated without having the resultant head of water raised by such works, no matter how insignificant the elevation might be, tend to increase the flow into one or the other, or both of the great passes, at the expense of the smaller one. To prevent the enlargement of these passes, which was sure to ensue, as the first effect of such works, it became necessary to sill each of these great passes.

The mattress sills, which extend across the two great adjoining passes, the Southwest Pass and the Pass A L'Outre, connect the system of works with the east and west shore of the Mississippi. These sills are simply submerged dams.

It should be stated that the Pass A L'Outre sill was not sunk until after considerable scour had taken place, under the influence of contracting that pass by the East Dyke, and that scour had also been observed on the eastern part of the Southwest Pass before it was silled.

A complete display of the effects of all the works constructed since December, 1875, is made by the areas of scour and deposit, which are exhibited on Plate XL.

The gradation on the fills is made in vertical offsets of five feet. The blank spaces denote scour, the amount being inserted in feet and tenths of feet. The neutral areas on which there has been no scour and no deposit are expressed by one faint tint.

With the aid of these explanations, a brief study of the chart will clearly reveal the causes by which erosive power was obtained. They can be traced back to the increase of velocity, resulting from the head of water which was obtained above the line of the works.

Again, the closing and filling up of one of the two entrance channels of the South Pass, and the corresponding enlargement of the other. the encroachment of the current upon the western shore-line of the new channel, and the increase in the width of section resulting therefrom, all these points are plainly elucidated on the chart, and indicate that South Pass is most actively engaged in the efforts to regain its original section.

In briefly reviewing the work done at the head of the passes during the last year we may state that,

1st. The Lighthouse Dyke has been extended up-stream a distance of two hundred and eighty feet, thereby throwing the effects of concentration within three hundred feet of the twenty-six foot contour of the Mississippi.

2nd. The Southwest Pass sill has been raised in the following manner:

Two	tiers	of mattresses,	to a	point	1 855	feet	from	west	shore.
Three	"	"	"	"	1 785	"	"	"	"
Four	"	"	"	"	790	"	"	"	"

Thence the sill has been brought gradually to the surface, which is reached at the east end of West Dyke, four hundred and seventy-five feet from the west shore.

In this manner the area of Southwest Pass is permanently decreased to eighty and a half per cent. of its original size. The obstruction placed in the way of the current, although twenty-five feet below the surface, is clearly distinguished by the break in the current at the surface, and the smooth water above the sill.

Judging from experience elsewhere, it is quite probable that in the course of time sediment will be deposited above the sill, and that the bed of the pass will be permanently fixed at the hight of the mattress work.

The result of such an event, on the permanence of the deep channel into South Pass, cannot be questioned.

3d. The island dyke has been raised to the surface from the head of the island up stream to point *P*. This work was done with a view of protecting the channel from sediment, which, in cases of easterly winds, was carried from the soft mud flats, east of the dyke, and borne toward the channel.

4th. The island dyke has also been built on line *P.—R.* Originally it extended from point *P.* to New Cluster; but this part was torn down

in April, 1877, in order to restore the loss of volume, which South Pass had suffered as one of the temporary effects of choking its entrance to procure concentration.

The new direction, which deviates slightly from the original location, lies more in the thread of the current, and was selected to prevent the formation of an eddy on the west side of the dyke.

The original dyke was built in a temporary manner, by tilting mattresses and suspending them vertically against a row of piles. The new dyke is built up strongly by horizontal layers of mattresses.

5th. The "Upper Dam" is a recent addition to the system of works. It was designed with a view of increasing the depth into South Pass from twenty-four and a half feet (the present depth) to twenty-six feet; but it will also tend to restore to South Pass the orignal volume of 1875. The curved extension of the Island Dyke to point *T*, as shown in the broken line on the chart, is an auxiliary design, serving the same purpose.

I was in hopes of being enabled to show a more marked area of scour in the line of the new current, which is deflected from the west end of Upper Dam into the South Pass, but owing to the uncommon low stage of the Mississippi, in connection with the fact that the dam was only completed at a very recent date (June 4th, 1879), it could not justly be expected that effects should be produced so rapidly.

However, the arguments for the efficiency of Upper Dam and Island Dyke extension, to procure a least channel depth of twenty-six feet, are very strong, and seem to indicate an early realization of that depth.

The distance from point *T*, the west end of "Upper Dam," to the mean low water line on the opposite shore of Southwest Pass, measured at right angles to the current, is three thousand one hundred feet. In this space we crowd the volume of both Passes, the South and Southwest, and thus may produce the elements of an equation, by which to ascertain approximately the mean depth, which will be obtained on the concentrated section. Thus:

Mean area of section, South Pass................	22 000 square feet.
" " " Southwest Pass............	65 000 " "
Total........................	87 000 square feet.

$$\text{Mean depth} = \frac{87\ 000}{3\ 100} = 28.06 \text{ feet.}$$

With a mean depth of twenty-eight feet, and the probability of greater depths close to the point, where the volume finds relief from the

Some of the names of dams and dykes at the head of the Passes which appear in Mr. Corthell's paper, were recently changed by Mr. Eads. The following list gives the corresponding names in both papers;

Dam II is now called Lighthouse Dam.

T Head Dam I is now called Island Dyke.

T Head Dam II is now called Lighthouse Dyke.

head of water collected immediately above the line of the works, we may safely look for the day, not far distant, when we may say that a channel of thirty feet in depth will be obtained between the Mississippi river and the Gulf.

NOTE.—Since the presentation of the above paper at the convention at Cleveland, the following official information has been secured, and is added to complete the record:

1. On June 18th, 1879, a channel of 26 feet in depth, and at no point less than 200 feet wide, was obtained through the jetties.

2. On July 8th, 1879, a channel of 30 feet in depth, without regard to width, was obtained through the jetties. (See Plate XLI, Bar Survey by United States Engineers.)

3. On July 10, 1879, a navigable channel of 26 feet in depth was obtained at the head of the Pass, connecting the deep water in the Mississippi with the deep water of the South Pass.

Thus, in less than four years from the day on which work was begun, the final result aimed at has been accomplished, and there exists now at the mouth of the Mississippi a channel which will constitute the greatest commercial highway in the world.